University of Salford MANCHESTER

CRN: 32906

School of Computing, Science and Engineering

TRIMESTER ONE EXAMINATION

Programme(s):
MSc Transport Engineering & Planning

TRANSPORT ENGINEERING: PRINCIPLES & METHODOLOGIES P1

Wednesday 10 January 2018 14:00 – 17:00

Instructions to Candidates

There are SIX questions in TWO sections, each of THREE questions.

You must answer **FOUR** questions. TWO must come from Section A and TWO from Section B.

All questions carry equal marks. The percentage allocation of marks within each question is as indicated.

Calculators may be used but **NOT** in text storage mode.

Extracts from the Design Manual for Roads and Bridges are provided.

Statistical formula sheets and tables are provided.

All Design Charts used (including the examination question paper) must be submitted with your answer book. Insert your Desk number on these charts. Clearly mark with pen and identify which of the design charts you have used in your answer.

For any missing information, make and state clearly any necessary assumptions.

Section A

1. Traffic Survey Design

a) With reference to the paper *Parkin, J. & Rotheram, J. (2010), Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal. Transport Policy, 17(5), 335-341*, identify and discuss the key elements of transport survey design and planning. Your answer should include a critical review of the approach taken by Parkin and Rotherham, noting any strengths and weaknesses, and should include an outline of possible alternatives and improvements.

(50% of Marks)

b)

(i) A concrete specification requires a minimum compressive strength of 36 MN/m^2 at 28 days below which not more than 1% of individual cube test results will be allowed to fall. Experience suggests that the type of plant and supervision likely to be used on the site will result in a coefficient of variation of 15%. Estimate the desired working average compressive strength.

(25% of Marks)

(ii) If the process is producing concrete with the desired mean and standard deviation of compressive strength, what is the probability that of 20 cubes made, none will fail below the minimum compressive strength?

(25% of Marks)

2. Design of Road Layouts

A single intersection is to be controlled by a fixed time signal having a cycle of 60 seconds. From one of the legs there is a right turning movement of 135 veh/h. These right turners represent 25% of all vehicles arriving at the junction from that leg. The layout of the intersection is such that three right turning vehicles/cycle can be satisfactorily handled without difficulty, whereas four or more right turning vehicles/cycle causes delays to other traffic.

(i) In what % of the cycles would delays occur?

(40% of Marks)

(ii) If at the above intersection a special right turning phase is provided, in what % of the cycles will this special feature be unnecessary by virtue of the fact that there is no right turning vehicle?

(10% of Marks)

(iii) Comment on the need to make any alterations to the junction based on the results from parts (i) and (ii) above.

(20% of Marks)

(iv) What is the probability that a random sample of 10 vehicles arriving at the junction from the main arm contains at least three right turners?

(30% of Marks)

3. Traffic Monitoring and Surveys

A new "Weigh in Motion" technique is to be adopted by police to monitor any excess axle loads from heavy goods vehicles passing over an old bridge. This technique consists of a portable weighing pad fitted on the road surface and connected to sensors which give axle load readings while the vehicle is travelling with any speed.

Before this new technique was adopted, a survey was conducted to compare its accuracy with that of a conventional method where a "Stationary Weighing Platform" is used. The survey was carried out as two sets with 8 pairs of readings of axle loads recorded for each set. The first set of readings were for vehicles moving with speeds less than 10 mph and for the stationary condition; and the second set were for those vehicles travelling with speeds in excess of 10 mph and again for the stationary condition. The following results were obtained:

"Stationary" versus "Weigh in Motion, Speed <10mph"

First Set	1	2	3	4	5	6	7	8
"Stationary" (x1000kg)	4.5	3.8	6.0	4.4	5.5	8.0	7.1	3.9
"In Motion" with speeds <10 mph (x1000kg)	4.3	3.9	6.2	4.0	5.6	8.0	7.0	4.0

"Stationary" versus "Weigh in Motion, Speed >10mph"

Second Set	1	2	3	4	5	6	7	8
"Stationary" (x1000kg)	5.5	4.9	5.1	3.4	4.5	5.2	8.8	7.7
"In Motion" with speeds >10 mph (x1000kg)	5.3	4.6	5.0	3.0	4.4	5.0	8.4	7.6

Test whether there is any difference between the means of the two techniques. Comment on the accuracy of the new system.

(100% of Marks)

Section B

4. Safety Engineering/Railway Engineering

a) A major/minor priority T-junction has been formed by linking a single carriageway (S2) from the East to a dual carriageway (D2) which runs North to South. There is concern about the high number of right turn conflicts at the junction. Discuss the design approach adopted in the Design Manual for Roads and Bridges for:

- providing the necessary visibility for minor road vehicles
- regulating the priority within the central reserve

(30% of Marks)

b) Identify the most common causes of accidents on the heavy rail network, list the factors associated with these accidents and describe and discuss measures to reduce their occurrence.

(70% of Marks)

5. Safety Engineering/Design and Layout of Highway Junctions

Consider the following different types of three-arm intersection:

- a free-flow motorway to motorway interchange
- a grade-separated two-bridge roundabout
- a T-junction connecting a single carriageway minor arm to a dual carriageway major arm

a) For each case discuss the design and layout factors which influence road safety at the intersection.

(70% of Marks)

b) Briefly compare the alternative layouts from the point of view of cost, operation and likely environmental impact, for a given level of flow.

(30% of Marks)

6. Pavement Design

a) Select five secondary and recycled materials which could be used in road construction and maintenance and show where each one is used as part of the pavement layers

(20% of Marks)

b) Explain briefly what these abbreviations stand for outlining their relevance in the field of Pavement Design and Construction: AADF, CBR, DBM, HBM, msa, OGV2, SCRIM and SMA?

(20% of Marks)

c) A new 3.6 km dual carriageway link road is to be built. Soil investigation reports show that the first 3.3 km section of the road has subgrade which mainly consists of clay with a Plasticity Index of 30%, whereas the rest of the section is mainly made up of heavy clay with a minimum Plasticity Index of 60%. There is a requirement that the weaker section of the road consisting of heavy clay needs to be treated and brought up to similar strength of that of the other section before the main construction starts.

Use the information provided in the handouts to suggest a detailed design showing the thickness of each layer and material used, starting at the formation level. Assume the following:

- design requirement is to use flexible with asphalt base type HDM50 material,
- water table level is at least 1 metre down, and
- using thin construction with average to good quality of drainage.

(Note: Make clear any other assumptions you have made. Submit all Design Manual for Roads and Bridges - DMRB design charts and tables together with your answer book. Clearly mark and identify all the design charts that you have used in your answer).

(60% of Marks)

Statistics Formulae

Mean, variance, coefficient of variation, skewness and kurtosis

$$\text{mean}: \ \bar{x} = \frac{1}{n}\sum f_i x_i$$

$$\text{variance}: \ s^2 = \frac{1}{n-1}\sum f_i\left(x_i - \bar{x}\right)^2 = \frac{1}{n-1}\left(\sum f_i x_i^2 - \frac{\left(\sum f_i x_i\right)^2}{n}\right)$$

$$skewness = 1/n\sum f_i\left(\frac{x_i - \bar{x}}{s}\right)^3$$

$$kurtosis = \left[1/n\sum f_i\left(\frac{x_i - \bar{x}}{s}\right)^4\right] - 3$$

Coefficient of variation = [(standard deviation) / (mean)] x 100%

Estimation of Covariance

If X, Y are random variables and (x_i, y_i) for i =1 to n denote n pairs of observations of the variables, then the covariance of X and Y is estimated by

$$\operatorname{cov}(X,Y) = \frac{1}{n-1}\sum_{i=1}^{n}\left((x_i - \bar{x})(y_i - \bar{y})\right) = \frac{1}{n-1}\left[\left(\sum_{i=1}^{n} x_i y_i\right) - \frac{\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n}\right]$$

If Z = X + Y

$\therefore$ var(Z) = var (X) + 2cov (X,Y) + var(Y)

If Z = X - Y

$\therefore$ var(Z) = var (X) - 2cov (X,Y) + var(Y)

Laws of probability

If A and B are any two events

P(A or B) = P(A + B) = P(A) + P(B) - P(AB)

P(A and B) = P (AB) = P(A) P(B/A)

Binomial distribution

If n independent trials are made of an event with a constant probability, p of success in each trial:

$$P(r \text{ successes}) = {}_nC_r \ p^r \ (1-p)^{n-r} = \frac{n(n-1)(n-2)\ldots(n-(r-1))}{(1)(2)(3)\ldots(r)} \ p^r \ (1-p)^{n-r}$$

mean number of successes = np;

variance of number of successes = np (1- p)

Poisson distribution

If the average number of occurrences of a random event in unit time is m:

P (r occurrences in unit time) = $e^{-m} m^r / r!$

Mean number of occurrences = m

Variance of number of occurrences = m

The probability of a time interval t between successive occurrences is me^{-mt} dt; the mean interval is (1/m); the variance of t is $(1/m)^2$.

The z and t distributions

In the following: n = sample size; $\bar{x}$ = sample mean; s^2 = sample estimate of population variance. Parent population is normal.

$z = (x - \mu) / \sigma$

where μ and σ are the population mean and standard deviation, respectively.

If population mean = μ,

$$t = \frac{\bar{x} - \mu}{s / \sqrt{n}}$$, is distributed as Student's $t_{(n-1)}$ with (n - 1) degrees of freedom

Estimation of population mean

100 (1 - a)% confidence interval for μ is given by

$$\bar{x} - z_{a/2} \frac{s}{\sqrt{n}} < \mu < \bar{x} + z_{a/2} \frac{s}{\sqrt{n}}$$ where $z_{a/2}$ is the Standard Normal Deviate

$$\bar{x} - t^{(n-1)}_{a/2} \frac{s}{\sqrt{n}} < \mu < \bar{x} + t^{(n-1)}_{a/2} \frac{s}{\sqrt{n}}$$

Estimating the difference between two population means (μ_1, μ_2)

100 (1-a)% confidence interval for $\mu_1 - \mu_2$ is given by

$$(\bar{x}_1 - \bar{x}_2) - z_{a/2} \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}} < (\mu_1 - \mu_2) < (\bar{x}_1 - \bar{x}_2) + z_{a/2} \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$$

[or replace z by t for small samples].

For paired observations:

$$\bar{d} - t^{(n-1)}_{a/2} \frac{s_D}{\sqrt{n}} < \mu_D < \bar{d} + t^{(n-1)}_{a/2} \frac{s_D}{\sqrt{n}}$$

where d represents the difference between paired observations and μ_d is the difference in population means.

The F test

If population variances are equal, $F = (s_1^2) / (s_2^2)$ is distributed as the variance ratio with $DF_1 = n_1 - 1$ and $DF_2 = n_2 - 1$.

Note: For use of most F tables, the larger estimate of variance must be in the numerator of the ratio.

Note also: $F_{(1-a)}(DF_1, DF_2) = 1 / F_{(a)}(DF_2, DF_1)$

If s_1^2 and s_2^2 are the estimates of variance derived from a particular pair of independent samples, a 95% confidence interval for σ_1^2 / σ_2^2 is given by

$$\frac{s_1^2}{s_2^2}\left(\frac{1}{F_{.025}(n_1-1,\ n_2-1)}\right) \le \frac{\sigma_1^2}{\sigma_2^2} \le \frac{s_1^2}{s_2^2}\left(F_{.025}(n_2-1,\ n_1-1)\right)$$

The Chi^2 (χ^2) test

$(n - 1)s^2/\sigma^2$ is distributed as $\chi^2(n-1)$ if the sample is independent drawing from a normal population.

Goodness of fit: If O_r, for $r = 1$ to n, denotes the observed frequency in the r^{th} class and if E_r denotes the corresponding expected frequency based on some specified hypothetical distribution, then

$\chi^2 = \Sigma\,[(O_r - E_r)^2 / E_r]$ is approximately distributed as $\chi^2_{(n-k-1)}$, where k is the number of parameters required to be estimated from the observed data in order that the expected frequencies may be estimated.

In a m x n contingency Table, the number of degrees of freedom is (m -1) x (n -1).
Note: All Expected frequencies should be ≥ 5.

To estimate a 100 (1-a)% confidence interval for σ^2 is given by:

$$(n-1)s^2/\chi^2_{(1-a/2)}(n-1) \le \sigma^2 \le (n-1)s^2/\chi^2_{(a/2)}(n-1)$$

Choice of sample size

The following equations are used to estimate the minimum sample size (n) required to estimate population means, proportions, ...etc.:

$n = [\,Z_{a/2}\,]^2\,[\sigma/d]^2$ for infinite population size

where $d \ge |\,\bar{x} - \mu\,|$

For proportions: $n = [(\,Z_{a/2}\,)/d]^2\,[p\,(1-p)\,]$

where $d \ge |\,p - \hat{p}\,|$

Assuming parent population is of size N:

$n = n_o / [1 + (n_o - 1) / N]$

Table I

CUMULATIVE NORMAL PROBABILITIES

z	F(z)	z	F(z)	z	F(z)	z	F(z)
.00	.5000000	.21	.5831662	.42	.6627573	.63	.7356527
.01	.5039894	.22	.5870644	.43	.6664022	.64	.7389137
.02	.5079783	.23	.5909541	.44	.6700314	.65	.7421539
.03	.5119665	.24	.5948349	.45	.6736448	.66	.7453731
.04	.5159534	.25	.5987063	.46	.6772419	.67	.7485711
.05	.5199388	.26	.6025681	.47	.6808225	.68	.7517478
.06	.5239222	.27	.6064199	.48	.6843863	.69	.7549029
.07	.5279032	.28	.6102612	.49	.6879331	.70	.7580363
.08	.5318814	.29	.6140919	.50	.6914625	.71	.7611479
.09	.5358564	.30	.6179114	.51	.6949743	.72	.7642375
.10	.5398278	.31	.6217195	.52	.6984682	.73	.7673049
.11	.5437953	.32	.6255158	.53	.7019440	.74	.7703500
.12	.5477584	.33	.6293000	.54	.7054015	.75	.7733726
.13	.5517168	.34	.6330717	.55	.7088403	.76	.7763727
.14	.5556700	.35	.6368307	.56	.7122603	.77	.7793501
.15	.5596177	.36	.6405764	.57	.7156612	.78	.7823046
.16	.5635595	.37	.6443088	.58	.7190427	.79	.7852361
.17	.5674949	.38	.6480273	.59	.7224047	.80	.7881446
.18	.5714237	.39	.6517317	.60	.7257469	.81	.7910299
.19	.5753454	.40	.6554217	.61	.7290691	.82	.7938919
.20	.5792597	.41	.6590970	.62	.7323711	.83	.7967306

Table I (continued)

z	F(z)	z	F(z)	z	F(z)	z	F(z)
.84	.7995458	1.32	.9065825	1.79	.9632730	2.26	.9880894
.85	.8023375	1.33	.9082409	1.80	.9640697	2.27	.9883962
.86	.8051055	1.34	.9098773	1.81	.9648521	2.28	.9886962
.87	.8078498	1.35	.9114920	1.82	.9656205	2.29	.9889893
.88	.8105703	1.36	.9130850	1.83	.9663750	2.30	.9892759
.89	.8132671	1.37	.9146565	1.84	.9671159	2.31	.9895559
.90	.8159399	1.38	.9162067	1.85	.9678432	2.32	.9898296
.91	.8185887	1.39	.9177356	1.86	.9685572	2.33	.9900969
.92	.8212136	1.40	.9192433	1.87	.9692581	2.34	.9903581
.93	.8238145	1.41	.9207302	1.88	.9699460	2.35	.9906133
.94	.8263912	1.42	.9221962	1.89	.9706210	2.36	.9908625
.95	.8289439	1.43	.9236415	1.90	.9712834	2.37	.9911060
.96	.8314724	1.44	.9250663	1.91	.9719334	2.38	.9913437
.97	.8339768	1.45	.9264707	1.92	.9725711	2.39	.9915758
.98	.8364569	1.46	.9278550	1.93	.9731966	2.40	.9918025
.99	.8389129	1.47	.9292191	1.94	.9738102	2.41	.9920237
1.00	.8413447	1.48	.9305634	1.95	.9744119	2.42	.9922397
1.01	.8437524	1.49	.9318879	1.96	.9750021	2.43	.9924506
1.02	.8461358	1.50	.9331928	1.97	.9755808	2.44	.9926564
1.03	.8484950	1.51	.9344783	1.98	.9761482	2.45	.9928572
1.04	.8508300	1.52	.9357445	1.99	.9767045	2.46	.9930531
1.05	.8531409	1.53	.9369916	2.00	.9772499	2.47	.9932443
1.06	.8554277	1.54	.9382198	2.01	.9777844	2.48	.9934309
1.07	.8576903	1.55	.9394292	2.02	.9783083	2.49	.9936128
1.08	.8599289	1.56	.9406201	2.03	.9788217	2.50	.9937903
1.09	.8621434	1.57	.9417924	2.04	.9793248	2.51	.9939634
1.10	.8643339	1.58	.9429466	2.05	.9798178	2.52	.9941323
1.11	.8665005	1.59	.9440826	2.06	.9803007	2.53	.9942969
1.12	.8686431	1.60	.9452007	2.07	.9807738	2.54	.9944574
1.13	.8707619	1.61	.9463011	2.08	.9812372	2.55	.9946139
1.14	.8728568	1.62	.9473839	2.09	.9816911	2.56	.9947664
1.15	.8749281	1.63	.9484493	2.10	.9821356	2.57	.9949151
1.16	.8769756	1.64	.9494974	2.11	.9825708	2.58	.9950600
1.17	.8789995	1.65	.9505285	2.12	.9829970	2.59	.9952012
1.18	.8809999	1.66	.9515428	2.13	.9834142	2.60	.9953388
1.19	.8829768	1.67	.9525403	2.14	.9838226	2.70	.9965330
1.20	.8849303	1.68	.9535213	2.15	.9842224	2.80	.9974449
1.21	.8868606	1.69	.9544860	2.16	.9846137	2.90	.9981342
1.22	.8887676	1.70	.9554345	2.17	.9849966	3.00	.9986501
1.23	.8906514	1.71	.9563671	2.18	.9853713	3.20	.9993129
1.24	.8925123	1.72	.9572838	2.19	.9857379	3.40	.9996631
1.25	.8943502	1.73	.9581849	2.20	.9860966	3.60	.9998409
1.26	.8961653	1.74	.9590705	2.21	.9864474	3.80	.9999277
1.27	.8979577	1.75	.9599408	2.22	.9867906	4.00	.9999683
1.28	.8997274	1.76	.9607961	2.23	.9871263	4.50	.9999966
1.29	.9014747	1.77	.9616364	2.24	.9874545	5.00	.9999997
1.30	.9031995	1.78	.9624620	2.25	.9877755	5.50	.9999990

Table II

UPPER PERCENTAGE POINTS OF THE t DISTRIBUTION

ν	$Q = 0.4$ $2Q = 0.8$	0.25 0.5	0.1 0.2	0.05 0.1	0.025 0.05	0.01 0.02	0.005 0.01	0.001 0.002
1	0.325	1.000	3.078	6.314	12.706	31.821	63.657	318.31
2	.289	0.816	1.886	2.920	4.303	6.965	9.925	22.326
3	.277	.765	1.638	2.353	3.182	4.541	5.841	10.213
4	.271	.741	1.533	2.132	2.776	3.747	4.604	7.173
5	0.267	0.727	1.476	2.015	2.571	3.365	4.032	5.893
6	.265	.718	1.440	1.943	2.447	3.143	3.707	5.208
7	.263	.711	1.415	1.895	2.365	2.998	3.499	4.785
8	.262	.706	1.397	1.860	2.306	2.896	3.355	4.501
9	.261	.703	1.383	1.833	2.262	2.821	3.250	4.297
10	0.260	0.700	1.372	1.812	2.228	2.764	3.169	4.144
11	.260	.697	1.363	1.796	2.201	2.718	3.106	4.025
12	.259	.695	1.356	1.782	2.179	2.681	3.055	3.930
13	.259	.694	1.350	1.771	2.160	2.650	3.012	3.852
14	.258	.692	1.345	1.761	2.145	2.624	2.977	3.787
15	0.258	0.691	1.341	1.753	2.131	2.602	2.947	3.733
16	.258	.690	1.337	1.746	2.120	2.583	2.921	3.686
17	.257	.689	1.333	1.740	2.110	2.567	2.898	3.646
18	.257	.688	1.330	1.734	2.101	2.552	2.878	3.610
19	.257	.688	1.328	1.729	2.093	2.539	2.861	3.579
20	0.257	0.687	1.325	1.725	2.086	2.528	2.845	3.552
21	.257	.686	1.323	1.721	2.080	2.518	2.831	3.527
22	.256	.686	1.321	1.717	2.074	2.508	2.819	3.505
23	.256	.685	1.319	1.714	2.069	2.500	2.807	3.485
24	.256	.685	1.318	1.711	2.064	2.492	2.797	3.467
25	0.256	0.684	1.316	1.708	2.060	2.485	2.787	3.450
26	.256	.684	1.315	1.706	2.056	2.479	2.779	3.435
27	.256	.684	1.314	1.703	2.052	2.473	2.771	3.421
28	.256	.683	1.313	1.701	2.048	2.467	2.763	3.408
29	.256	.683	1.311	1.699	2.045	2.462	2.756	3.396
30	0.256	0.683	1.310	1.697	2.042	2.457	2.750	3.385
40	.255	.681	1.303	1.684	2.021	2.423	2.704	3.307
60	.254	.679	1.296	1.671	2.000	2.390	2.660	3.232
120	.254	.677	1.289	1.658	1.980	2.358	2.617	3.160
∞	.253	.674	1.282	1.645	1.960	2.326	2.576	3.090

Table III

UPPER PERCENTAGE POINTS OF THE χ^2 DISTRIBUTION

ν \ Q	0.995	0.990	0.975	0.950	0.900	0.750	0.500
1	392704.10^{-10}	157088.10^{-9}	982069.10^{-9}	393214.10^{-8}	0.0157908	0.1015308	0.454937
2	0.0100251	0.0201007	0.0506356	0.102587	0.210720	0.575364	1.38629
3	0.0717212	0.114832	0.215795	0.351846	0.584375	1.212534	2.36597
4	0.206990	0.297110	0.484419	0.710721	1.063623	1.92255	3.35670
5	0.411740	0.554300	0.831211	1.145476	1.61031	2.67460	4.35146
6	0.675727	0.872085	1.237347	1.63539	2.20413	3.45460	5.34812
7	0.989265	1.239043	1.68987	2.16735	2.83311	4.25485	6.34581
8	1.344419	1.646482	2.17973	2.73264	3.48954	5.07064	7.34412
9	1.734926	2.087912	2.70039	3.32511	4.16816	5.89883	8.34283
10	2.15585	2.55821	3.24697	3.94030	4.86518	6.73720	9.34182
11	2.60321	3.05347	3.81575	4.57481	5.57779	7.58412	10.3410
12	3.07382	3.57056	4.40379	5.22603	6.30380	8.43842	11.3403
13	3.56503	4.10691	5.00874	5.89186	7.04150	9.29906	12.3398
14	4.07468	4.66043	5.62872	6.57063	7.78953	10.1653	13.3393
15	4.60094	5.22935	6.26214	7.26094	8.54675	11.0365	14.3389
16	5.14224	5.81221	6.90766	7.96164	9.31223	11.9122	15.3385
17	5.69724	6.40776	7.56418	8.67176	10.0852	12.7919	16.3381
18	6.26481	7.01491	8.23075	9.39046	10.8649	13.6753	17.3379
19	6.84398	7.63273	8.90655	10.1170	11.6509	14.5620	18.3376
20	7.43386	8.26040	9.59083	10.8508	12.4426	15.4518	19.3374
21	8.03366	8.89720	10.28293	11.5913	13.2396	16.3444	20.3372
22	8.64272	9.54249	10.9823	12.3380	14.0415	17.2396	21.3370
23	9.26042	10.19567	11.6885	13.0905	14.8479	18.1373	22.3369
24	9.88623	10.8564	12.4011	13.8484	15.6587	19.0372	23.3367
25	10.5197	11.5240	13.1197	14.6114	16.4734	19.9393	24.3366
26	11.1603	12.1981	13.8439	15.3791	17.2919	20.8434	25.3364
27	11.8076	12.8786	14.5733	16.1513	18.1138	21.7494	26.3363
28	12.4613	13.5648	15.3079	16.9279	18.9392	22.6572	27.3363
29	13.1211	14.2565	16.0471	17.7083	19.7677	23.5666	28.3362
30	13.7867	14.9535	16.7908	18.4926	20.5992	24.4776	29.3360
40	20.7065	22.1643	24.4331	26.5093	29.0505	33.6603	39.3354
50	27.9907	29.7067	32.3574	34.7642	37.6886	42.9421	49.3349
60	35.5346	37.4848	40.4817	43.1879	46.4589	52.2938	59.3347
70	43.2752	45.4418	48.7576	51.7393	55.3290	61.6983	69.3344
80	51.1720	53.5400	57.1532	60.3915	64.2778	71.1445	79.3343
90	59.1963	61.7541	65.6466	69.1260	73.2912	80.6247	89.3342
100	67.3276	70.0648	74.2219	77.9295	82.3581	90.1332	99.3341
z_Q	−2.5758	−2.3263	−1.9600	−1.6449	−1.2816	−0.6745	0.0000

Table III (continued)

ν \ Q	0.250	0.100	0.050	0.025	0.010	0.005	0.001
1	1.32330	2.70554	3.84146	5.02389	6.63490	7.87944	10.828
2	2.77259	4.60517	5.99147	7.37776	9.21034	10.5966	13.816
3	4.10835	6.25139	7.81473	9.34840	11.3449	12.8381	16.266
4	5.38527	7.77944	9.48773	11.1433	13.2767	14.8602	18.467
5	6.62568	9.23635	11.0705	12.8325	15.0863	16.7496	20.515
6	7.84080	10.6446	12.5916	14.4494	16.8119	18.5476	22.458
7	9.03715	12.0170	14.0671	16.0128	18.4753	20.2777	24.322
8	10.2188	13.3616	15.5073	17.5346	20.0902	21.9550	26.125
9	11.3887	14.6837	16.9190	19.0228	21.6660	23.5893	27.877
10	12.5489	15.9871	18.3070	20.4831	23.2093	25.1882	29.588
11	13.7007	17.2750	19.6751	21.9200	24.7250	26.7569	31.264
12	14.8454	18.5494	21.0261	23.3367	26.2170	28.2995	32.909
13	15.9839	19.8119	22.3621	24.7356	27.6883	29.8194	34.528
14	17.1170	21.0642	23.6848	26.1190	29.1413	31.3193	36.123
15	18.2451	22.3072	24.9958	27.4884	30.5779	32.8013	37.697
16	19.3688	23.5418	26.2962	28.8454	31.9999	34.2672	39.252
17	20.4887	24.7690	27.5871	30.1910	33.4087	35.7185	40.790
18	21.6049	25.9894	28.8693	31.5264	34.8053	37.1564	42.312
19	22.7178	27.2036	30.1435	32.8523	36.1908	38.5822	43.820
20	23.8277	28.4120	31.4104	34.1696	37.5662	39.9968	45.315
21	24.9348	29.6151	32.6705	35.4789	38.9321	41.4010	46.797
22	26.0393	30.8133	33.9244	36.7807	40.2894	42.7956	48.268
23	27.1413	32.0069	35.1725	38.0757	41.6384	44.1813	49.728
24	28.2412	33.1963	36.4151	39.3641	42.9798	45.5585	51.179
25	29.3389	34.3816	37.6525	40.6465	44.3141	46.9278	52.620
26	30.4345	35.5631	38.8852	41.9232	45.6417	48.2899	54.052
27	31.5284	36.7412	40.1133	43.1944	46.9630	49.6449	55.476
28	32.6205	37.9159	41.3372	44.4607	48.2782	50.9933	56.892
29	33.7109	39.0875	42.5569	45.7222	49.5879	52.3356	58.302
30	34.7998	40.2560	43.7729	46.9792	50.8922	53.6720	59.703
40	45.6160	51.8050	55.7585	59.3417	63.6907	66.7659	73.402
50	56.3336	63.1671	67.5048	71.4202	76.1539	79.4900	86.661
60	66.9814	74.3970	79.0819	83.2976	88.3794	91.9517	99.607
70	77.5766	85.5271	90.5312	95.0231	100.425	104.215	112.317
80	88.1303	96.5782	101.879	106.629	112.329	116.321	124.839
90	98.6499	107.565	113.145	118.136	124.116	128.299	137.208
100	109.141	118.498	124.342	129.561	135.807	140.169	149.449
z_Q	+0.6745	+1.2816	+1.6449	+1.9600	+2.3263	+2.5758	+3.0902

F distribution

Table IV (continued)

UPPER 2.5% POINTS

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	647.8	799.5	864.2	899.6	921.8	937.1	948.2	956.7	963.3	968.6	976.7	984.9	993.1	997.2	1001	1006	1010	1014	1018
2	38.51	39.00	39.17	39.25	39.30	39.33	39.36	39.37	39.39	39.40	39.41	39.43	39.45	39.46	39.46	39.47	39.48	39.49	39.50
3	17.44	16.04	15.44	15.10	14.88	14.73	14.62	14.54	14.47	14.42	14.34	14.25	14.17	14.12	14.08	14.04	13.99	13.95	13.90
4	12.22	10.65	9.98	9.60	9.36	9.20	9.07	8.98	8.90	8.84	8.75	8.66	8.56	8.51	8.46	8.41	8.36	8.31	8.26
5	10.01	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68	6.62	6.52	6.43	6.33	6.28	6.23	6.18	6.12	6.07	6.02
6	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52	5.46	5.37	5.27	5.17	5.12	5.07	5.01	4.96	4.90	4.85
7	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82	4.76	4.67	4.57	4.47	4.42	4.36	4.31	4.25	4.20	4.14
8	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36	4.30	4.20	4.10	4.00	3.95	3.89	3.84	3.78	3.73	3.67
9	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03	3.96	3.87	3.77	3.67	3.61	3.56	3.51	3.45	3.39	3.33
10	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78	3.72	3.62	3.52	3.42	3.37	3.31	3.26	3.20	3.14	3.08
11	6.72	5.26	4.63	4.28	4.04	3.88	3.76	3.66	3.59	3.53	3.43	3.33	3.23	3.17	3.12	3.06	3.00	2.94	2.88
12	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44	3.37	3.28	3.18	3.07	3.02	2.96	2.91	2.85	2.79	2.72
13	6.41	4.97	4.35	4.00	3.77	3.60	3.48	3.39	3.31	3.25	3.15	3.05	2.95	2.89	2.84	2.78	2.72	2.66	2.60
14	6.30	4.86	4.24	3.89	3.66	3.50	3.38	3.29	3.21	3.15	3.05	2.95	2.84	2.79	2.73	2.67	2.61	2.55	2.49
15	6.20	4.77	4.15	3.80	3.58	3.41	3.29	3.20	3.12	3.06	2.96	2.86	2.76	2.70	2.64	2.59	2.52	2.46	2.40
16	6.12	4.69	4.08	3.73	3.50	3.34	3.22	3.12	3.05	2.99	2.89	2.79	2.68	2.63	2.57	2.51	2.45	2.38	2.32
17	6.04	4.62	4.01	3.66	3.44	3.28	3.16	3.06	2.98	2.92	2.82	2.72	2.62	2.56	2.50	2.44	2.38	2.32	2.25
18	5.98	4.56	3.95	3.61	3.38	3.22	3.10	3.01	2.93	2.87	2.77	2.67	2.56	2.50	2.44	2.38	2.32	2.26	2.19
19	5.92	4.51	3.90	3.56	3.33	3.17	3.05	2.96	2.88	2.82	2.72	2.62	2.51	2.45	2.39	2.33	2.27	2.20	2.13
20	5.87	4.46	3.86	3.51	3.29	3.13	3.01	2.91	2.84	2.77	2.68	2.57	2.46	2.41	2.35	2.29	2.22	2.16	2.09
21	5.83	4.42	3.82	3.48	3.25	3.09	2.97	2.87	2.80	2.73	2.64	2.53	2.42	2.37	2.31	2.25	2.18	2.11	2.04
22	5.79	4.38	3.78	3.44	3.22	3.05	2.93	2.84	2.76	2.70	2.60	2.50	2.39	2.33	2.27	2.21	2.14	2.08	2.00
23	5.75	4.35	3.75	3.41	3.18	3.02	2.90	2.81	2.73	2.67	2.57	2.47	2.36	2.30	2.24	2.18	2.11	2.04	1.97
24	5.72	4.32	3.72	3.38	3.15	2.99	2.87	2.78	2.70	2.64	2.54	2.44	2.33	2.27	2.21	2.15	2.08	2.01	1.94
25	5.69	4.29	3.69	3.35	3.13	2.97	2.85	2.75	2.68	2.61	2.51	2.41	2.30	2.24	2.18	2.12	2.05	1.98	1.91
26	5.66	4.27	3.67	3.33	3.10	2.94	2.82	2.73	2.65	2.59	2.49	2.39	2.28	2.22	2.16	2.09	2.03	1.95	1.88
27	5.63	4.24	3.65	3.31	3.08	2.92	2.80	2.71	2.63	2.57	2.47	2.36	2.25	2.19	2.13	2.07	2.00	1.93	1.85
28	5.61	4.22	3.63	3.29	3.06	2.90	2.78	2.69	2.61	2.55	2.45	2.34	2.23	2.17	2.11	2.05	1.98	1.91	1.83
29	5.59	4.20	3.61	3.27	3.04	2.88	2.76	2.67	2.59	2.53	2.43	2.32	2.21	2.15	2.09	2.03	1.96	1.89	1.81
30	5.57	4.18	3.59	3.25	3.03	2.87	2.75	2.65	2.57	2.51	2.41	2.31	2.20	2.14	2.07	2.01	1.94	1.87	1.79
40	5.42	4.05	3.46	3.13	2.90	2.74	2.62	2.53	2.45	2.39	2.29	2.18	2.07	2.01	1.94	1.88	1.80	1.72	1.64
60	5.29	3.93	3.34	3.01	2.79	2.63	2.51	2.41	2.33	2.27	2.17	2.06	1.94	1.88	1.82	1.74	1.67	1.58	1.48
120	5.15	3.80	3.23	2.89	2.67	2.52	2.39	2.30	2.22	2.16	2.05	1.94	1.82	1.76	1.69	1.61	1.53	1.43	1.31
∞	5.02	3.69	3.12	2.79	2.57	2.41	2.29	2.19	2.11	2.05	1.94	1.83	1.71	1.64	1.57	1.48	1.39	1.27	1.00

Handouts for question 6 – Transport Engineering: Principles & Methodologies
CRN: 32906

Extracts from the Design Manual for Roads and Bridges

Note: Insert your desk number on the Design Charts and submit them with your answer book.

Student's Desk Number ....

Table 1 Traffic Calculation

Commercial vehicle Class or category	AADF (F)	Growth Factor (G)	Wear Factor (W_N)	Weighted Annual Traffic (by class or by category)
Either by class Buses and Coaches (PSV)		1.19		
OGV1 2 axle rigid 3 axle rigid		 1.19 1.19		
OGV2 4 axle rigid 3 and 4 axle artic 5 axle artic 6 axle artic		 1.67 1.67 1.67 1.67		
Or by category OGV1 + PSV OGV2	 1100 950	 1.19 1.67		
Total daily flow (cv/d)		Total weighted annual traffic		
$T = 365 \times F \times Y \times G \times W \times P \times 10^{-6}$ msa		Percentage of vehicles in heaviest traffic lane (P)		
		Design Period (Y)		*40 years*
		Design Traffic (T)		

Weighted annual traffic = $365 \times F \times G \times W \times 10^{-6}$ msa
Design Traffic (T) = Total weighted annual traffic $\times Y \times P$

Wear Factor (W)

2.23 The structural wear to a road associated with each vehicle that passes increases significantly with increasing axle load. Although alternative methods are available, structural wear for pavement design purposes in the UK is taken as being proportional to the 4th power of the axle load, i.e:

Wear/axle $\propto L^4$
(L = axle load)

Thus, a 50% increase in axle load results in a five-fold increase in calculated structural wear.

2.24 A 'standard axle' is defined as an axle exerting or applying a force of 80kN. The fourth power law is used to equate the wear caused by each vehicle type to the number of equivalent standard axles, to give the structural wear factor of that vehicle.

2.25 Sets of wear factors have been produced for maintenance and new design cases; the wear factors for the new design case are higher than for the maintenance case in order to allow for the additional risk that arises from the additional uncertainty with traffic predictions for new designs.

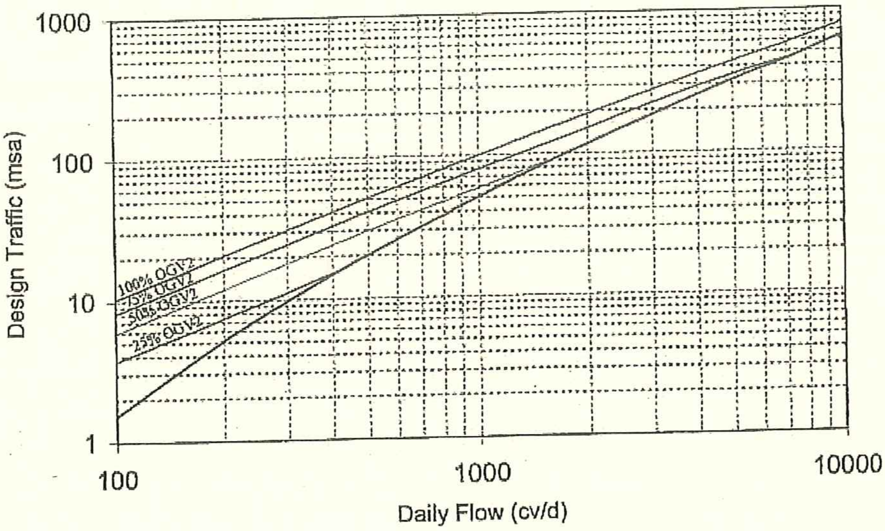
> 2.26 The wear factors to be used for the Maintenance (W_M), and New design (W_N) cases, are shown in Table 2.3. The derivation of these wear factors is given in TRL Report PPR 066 (2006).

Table 2.3 Wear Factors for cv Classes and Categories

Wear Factors	Maintenance W_M	New W_N
Buses and Coaches	2.6	3.9
2-axle rigid	0.4	0.6
3-axle rigid	2.3	3.4
4-axle rigid	3.0	4.6
3 and 4-axle articulated	1.7	2.5
5-axle articulated	2.9	4.4
6-axle articulated	3.7	5.6
OGV1 + PSV	0.6	1.0
OGV2	3.0	4.4

2.27 In Table 2.3, the data used to calculate the wear factors were obtained from twelve core census sites located throughout the Highways Agency's trunk road network and from traffic data collected in 2003.

> 2.28 The wear factors for the new road design case, W_N, shall be used to calculate design traffic for all new road and pavement construction projects including road widening.



Daily Flow (one-way) (cv/d)

Figure 2.2 Design Traffic for 40 Year Life

Growth Factor (G)

2.17 The National Road Traffic Forecast (NRTF) is published in eight year intervals and predicts future traffic trends. The 1997 NRTF growth lines shown for OGV1+PSV and for OGV2 (the bold lines on Figure 2.3) shall be used unless specific alternative and more reliable local data are available.

2.18 Past growth, where known from traffic counts, can also be used to give an indication of future trends in a particular situation, but only where data over at least a 10 year period are available, since averaging over a shorter period may give misleading results.

2.19 For each cv class or category, traffic growth can be calculated which is dependent on the selected design period and the growth rate. The growth factor represents the proportional difference between the average vehicle flow over the entire design period and the present flow (or flow at opening). The growth factor for future traffic shall be found by using Figure 2.3.

2.20 If past traffic is being calculated, the applicable growth factor is given in Figure 2.4. Bold lines are shown for OGV1+PSV and OGV2 which represent national trends. These bold lines are to be used unless actual growth rates are known for a specific cv class or category.

2.21 If a series of past traffic counts is available it is preferable to use these to calculate mean vehicle flows for each class between count dates. Under such circumstances a growth factor for past traffic is unnecessary and therefore effectively becomes 1.0.

2.22 The graphs for past traffic do not include adjustments for historic changes in wear factors. As an approximation, the current vehicle wear factors have been used to calculate growth factors.

2.32 The distribution of traffic between lanes can, under certain circumstances, vary considerably between different roads. The distribution can be influenced by traffic flow, by the proximity to junctions and on approaches to traffic signals and roundabouts.

2.33 For 2-lane roads, all traffic not in Lane 1 will be in Lane 2. For 3-lane roads, it should be considered that all commercial vehicles not in Lane 1 are in Lane 2 although commercial vehicles up to 7.5 tonnes are permitted to use the right hand lane. For roads with 4 or more lanes, data from a core census site or a traffic count shall be necessary to confirm the distribution of traffic across each lane.

Design Traffic (T)

2.34 The future cumulative flow, in terms of million standard axles (msa) for cv class T_i can be determined according to the following equation:

$T_i = 365 \times F \times Y \times G \times W \times P \times 10^{-6}$ msa

Design Traffic (T) = ΣT_i

Where:

F = Flow of Traffic (AADF) for each traffic class at opening
Y = Design Period (Years)
G = Growth Factor (from Figure 2.3)
P = Percentage of vehicles in the heaviest loaded lane (Figure 2.5)
W = Wear Factor for each traffic class (W_M for Maintenance or W_N for New Design Case) from Table 2.3

For past traffic, Y = years since opening; G = Growth Factor according to Figure 2.4.

If the calculation of traffic in other lanes is for maintenance purposes, P shall be the percentage of the commercial vehicles determined to be in each lane, refer to paragraph 2.33.

2.35 For new design cases, the calculation of design traffic is typically made by category, e.g.: OGV1 and OGV2.

2.36 Design traffic calculations can be made using the form shown in Table 2.4 and Tables 2.5 and 2.6 present two examples using Table 2.4 to calculate the design traffic (for new design and for maintenance).

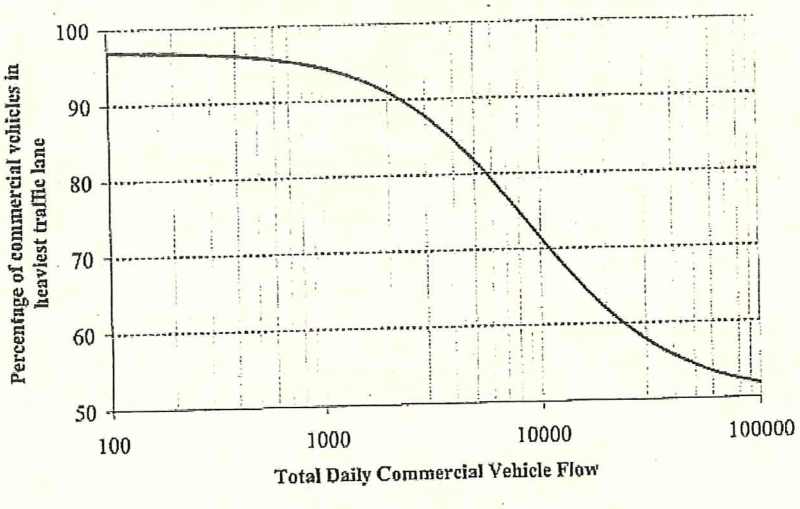


Figure 2.5 Percentage of Commercial Vehicles in Heaviest Loaded Lane (P)

3. CAPPING AND SUB-BASE

3.1 Capping is used to improve and protect weak subgrades by using a relatively cheap material between the subgrade and the sub-base. The aim is to increase the stiffness modulus and strength of the formation, on which the sub-base will be placed. Capping with a laboratory CBR value of at least 15% should provide an adequate platform for construction of the sub-base when compacted to the appropriate thickness.

3.2 Granular and cemented sub-bases are permitted for flexible and flexible composite pavements but only cemented sub-bases are permitted for rigid and rigid composite pavements.

3.3 The grading for unbound granular sub-base is intended to provide a dense layer of relatively high stiffness modulus, which is reasonably impermeable and will thus shed rain water during construction, given adequate fall. It is not necessarily free draining and may exhibit suction, and thus increase in moisture content. Granular sub-base with a laboratory CBR of at least 30% should provide an adequate platform for construction of the pavement when compacted to the appropriate thickness.

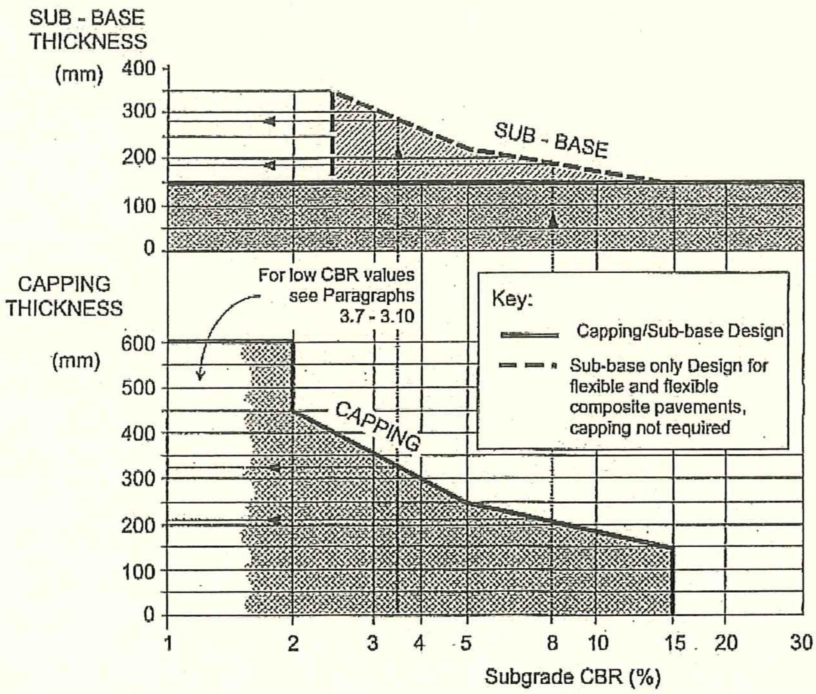


FIGURE 3.1 Capping and Sub-base Thickness Design

Example 1 : CBR	3.5%	Example 2 : CBR	8%
Alternative Designs		Alternative Designs	
a. Sub-base	150mm	a. Sub-base	150mm
on Capping	330mm	on Capping	210mm
b. Sub-base	280mm	b. Sub-base	190mm
No Capping		No Capping	

2.8 If full information is not available for Table 2.1 to be used, then certain assumptions can be made. The worst condition of a high water table can be taken together with construction being carried out to the Specification (MCHW1) and thus at least 'average' construction conditions pertain. The pavements discussed in this Section vary between "thick" and "thin" constructions; by interpolating between the values in Table 2.1, a table of acceptable Equilibrium Values can be derived. This is shown in Table 2.2. Background information on this table is available in HA 44/91 (DMRB 4.1.1). Table 2.2 should be used where full information is not available. The following methods may be used as a check for the CBR value, but shall only supersede the use of Tables 2.1 and 2.2 with the prior approval of the Overseeing Department.

Laboratory Testing

2.9 CBR values can be measured in the laboratory on recompacted specimens, in accordance with BS1377 (1990), during the site investigation stage and when the equipment and experience are available. Tests should be carried out over a range of conditions to reproduce, as far as possible, the conditions of moisture content and density which are likely to be experienced during construction and in the completed pavement. Cohesive soils should be compacted to not less than 5% air voids, to reproduce the likely conditions on site. Equilibrium moisture content can be deduced from measurements on a suction plate (LR889, 1979).

Site Testing

2.10 For design, the CBR must be estimated before construction commences. For fine grained soils in-situ CBR values can however be measured for checking purposes (not to allow design changes) in pits or on trial strips during construction. Equilibrium CBR values require the testing of existing pavements and HA 44/91 (DMRB 4.1.1) suggests a suitable procedure. Plate bearing tests are necessary for coarse materials (BS5930, 1981).

TYPE OF SOIL	PI	HIGH WATER TABLE						LOW WATER TABLE					
		CONSTRUCTION CONDITIONS:						CONSTRUCTION CONDITIONS:					
		POOR		AVERAGE		GOOD		POOR		AVERAGE		GOOD	
		Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
HEAVY CLAY	70	1½	2	2	2	2	2	1½	2	2	2	2	2½
	60	1½	2	2	2	2	2½	1½	2	2	2	2	2½
	50	1½	2	2	2½	2	2½	2	2	2	2½	2	2½
	40	2	2½	2½	3	2½	3	2½	2½	3	3	3	3½
SILTY CLAY	30	2½	3½	3	4	3½	5	3	3½	4	4	4	6
SANDY CLAY	20	2½	4	4	5	4½	7	3	4	5	6	6	8
	10	1½	3½	3	6	3½	7	2½	4	4½	7	6	>8
SILT*		1	1	1	1	2	2	1	1	2	2	2	2
SAND (POORLY GRADED)		20											
SAND (WELL GRADED)		40											
SANDY GRAVEL (WELL GRADED)		60											

* estimated assuming some probability of material saturating

TABLE 2.1 Equilibrium Subgrade CBR Estimation

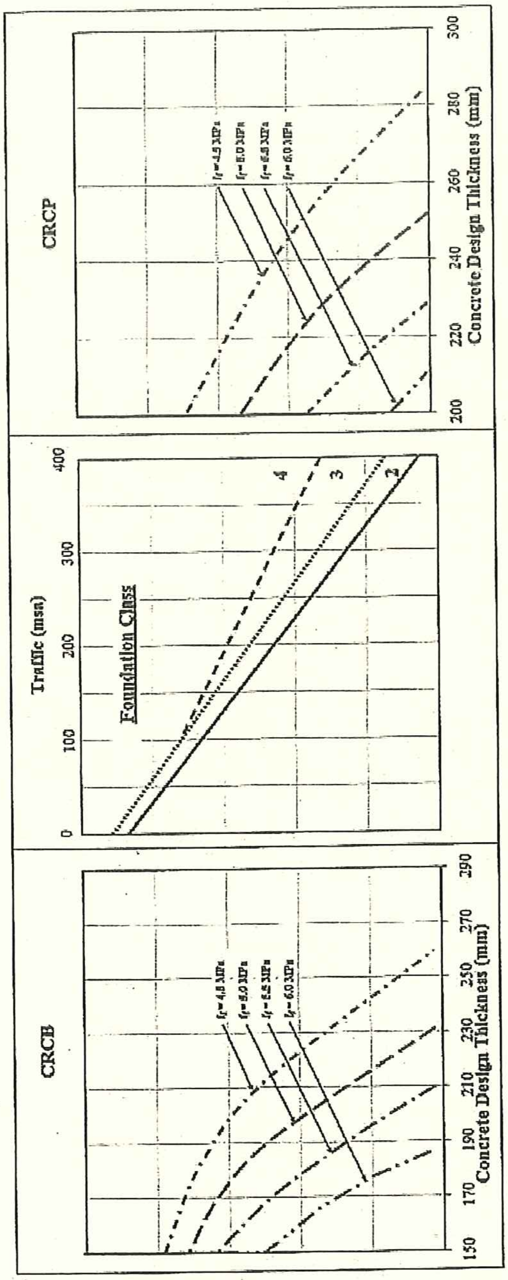
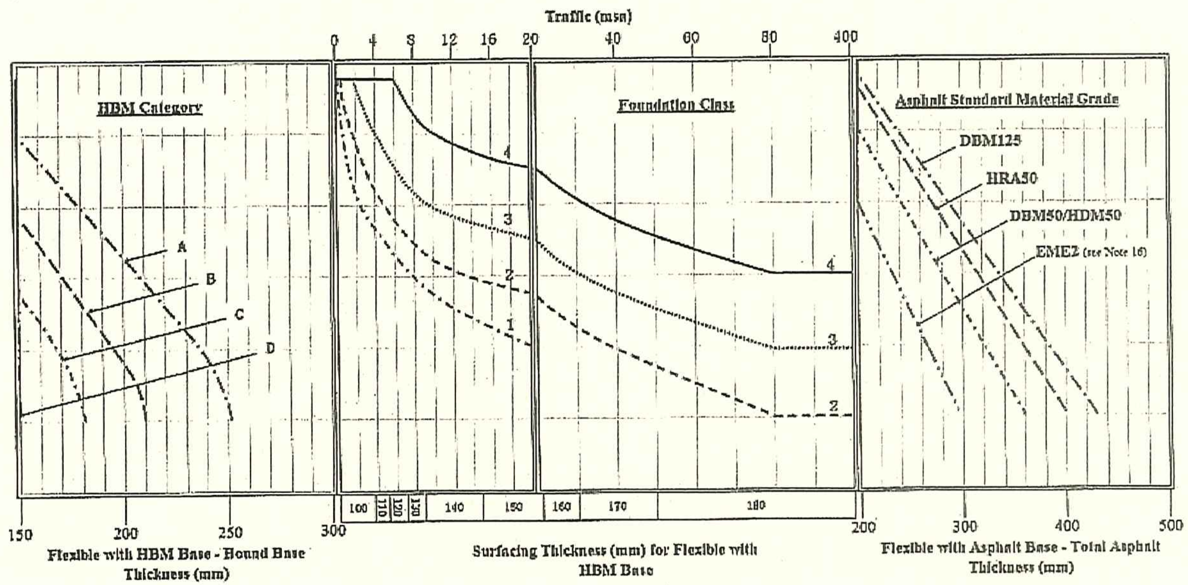


Figure 2.2: Design Thickness for Rigid (Continuous) Pavements



Examples of Hydraulic Bound Base Materials

HBM Category	A	B	C	D
Crushed Rock Coarse Aggregate: (with coefficient of thermal expansion <10 × 10 $^{-6}$ per °C)	-	CBGM B – C8/10 (or T3) SBM B1 – C9/12 (or T3) FABM1 – C9/12 (or T3)	CBGM B – C12/15 (or T4) SBM B1 – C12/16 (or T4) FABM1 – C12/16 (or T4)	CBGM B – C16/20 (or T5) SBM B1 – C15/20 (or T5) FABM1 – C15/20 (or T5)
Gravel Coarse Aggregate: (with coefficient of thermal expansion ≥10 × 10 $^{-6}$ per °C)	CBGM B – C8/10 (or T3) SBM B1 – C9/12 (or T3) FABM1 – C9/12 (or T3)	CBGM B – C12/15 (or T4) SBM B1 – C12/16 (or T4) FABM1 – C12/16 (or T4)	CBGM B – C16/20 (or T5) SBM B1 – C15/20 (or T5) FABM1 – C15/20 (or T5)	-

Figure 2.1 Design Thickness for Flexible Pavements